

Word Formatter for MVM'73 Real-Time High-Rate TV Data

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During both MVM'73 encounters, real-time TV data at 117.6 kilobits/s will be transmitted from DSS 14 to the Space Flight Operations Facility (SFOF) along a 230.4-kilobits/s supergroup line. The reliability of this link is largely an unknown parameter, but previous experience with similar data channels suggests that random (nonbursty) bit errors may occur at rates between 1 in 10^4 and 1 in 10^7 bits. The original design of the word formatter necessitated by the discrepancy between the source and ground transmission rates is shown to be inadequate to guarantee acceptable reception of the TV data at the SFOF. An alternative formatter design is described, which alleviates this problem with minimum cost changes from the original system.

I. Introduction

Current plans call for the transmission of the 117.6-kilobits/s imaging data from the 1973 Mariner Venus/Mercury (MVM'73) probe to the Space Flight Operations Facility (SFOF) during both planetary encounters. The ground leg of this telemetry link will consist of a 230.4-kilobits/s telephone company supergroup data line between the Goldstone 64-m tracking station (DSS 14) and the SFOF. This particular data channel has not been used before, so its reliability is largely an indeterminate parameter at this stage. However, for system design purposes, it is estimated that the link will have randomly distributed bit errors at rates between 1 in 10^4 and 1 in 10^7 bits, except in those rare periods when the errors occur in bursts.

To accommodate the mismatch between the information source and ground transmission rates, a hardware

device will stuff filler bits onto the data line at an average rate of 112.8 kilobits/s. The combined imaging data and filler bits will be organized into 18-bit words (bytes) prior to transmission, as described below. At the other end of the ground link, another piece of hardware will establish and maintain byte synchronization, and remove the filler bits to reconstruct the original TV data sequence. The combined hardware system for stuffing filler bits onto the ground link and then extracting them at the receive end is referred to as a "word formatter."

The purpose of this report is to analyze the original design of the word formatter, and to show that the resultant TV pictures would be likely to fall below minimum acceptable project standards. It will then be demon-

strated that a few inexpensive changes in this formatter design are sufficient to guarantee the required performance levels.

II. Original Formatter

A. Design

The transmit portion of the original formatter design is diagrammed in Fig. 1. Imaging data from the spacecraft are received at DSS 14 at 117.6 kilobits/s. The supergroup data link transmits information to the SFOF in 18-bit bytes at 230.4 kilobits/s. Because of the difference between the source and transmission rates, there are two kinds of bytes: data (D) and filler (F) bytes. The F byte is a fixed 18-bit sequence:

$$S = 001\ 010\ 000\ 000\ 000\ 000$$

stored in a shift register of that length. The D byte contains 16 bits of TV data, one extraneous bit which is always a 1, and a parity check bit P. In each D byte, the P bit is selected so that the 18 bits sum to 1 modulo 2; thus the D bytes have odd parity while the F bytes have even parity.

The Symbol Synchronizer Assembly (SSA) feeds imaging data in 16-bit blocks into the D-byte shift register at an average rate of 117.6 kilobits/s. Every 18/230.4 ms, an 18-bit byte is transferred to the supergroup data line for transmission. At these instants, if the data shift register is full, a D byte is sent; otherwise, the F byte is transmitted. Thus, approximately every other transmitted byte is an F byte. Furthermore, the transmitted data never contains two consecutive F or three consecutive D bytes, as emphasized in Fig. 1.

At the receive end of the ground link, the formatter must strip off the imaging data. This involves the acquisition and maintenance of byte synchronization, and the correct identification of D and F bytes. Acquiring byte synchronization is not a problem because almost every other transmitter byte is a known 18-bit filler sequence. Shifting one bit at a time, the synchronizer searches for an 18-bit received sequence that is identical to the transmitted F byte. Once this initial search is consummated, byte synchronization can be verified by checking successive F bytes.

To distinguish between D and F bytes, the formatter determines the parity of each received byte. This parity-check algorithm is also used to detect loss of byte synchronization resulting from the random deletion of data

or insertion of extraneous bits in the ground link. For a particular received byte, the algorithm operates as follows:

$$\begin{array}{l} \text{odd parity} \Rightarrow \text{D byte} \\ \text{even parity} \left\{ \begin{array}{l} \text{identical with F byte} \Rightarrow \text{F byte} \\ \text{does not agree with} \\ \text{F byte} \Rightarrow \text{loss of byte sync} \end{array} \right. \end{array}$$

When the algorithm decides byte synchronization is lost, the formatter reenters the byte sync acquisition (BSA) mode.

B. Performance

The imaging data extracted by the receive portion of the formatter are fed to a Univac 1230 computer that acquires and maintains frame synchronization. A frame of TV data contains 7056 bits, which translates into 1 line of video. Any time the formatter parity-check algorithm misinterprets a received F byte to be a D byte, the corresponding received frame of imaging data is augmented by 16 bits. This usually causes the frame synchronizer to drop lock, resulting in the loss of at least 1 line of video. Similarly, if a received D byte is judged to be an F byte, the frame is shortened by 16 bits, leading to a minimum loss of 1 line of video. Finally, there is a loss of at least 1 frame of TV data any time the formatter reverts to the BSA mode.

A "byte error" is defined as the event that a particular received byte is misinterpreted or causes the formatter to reenter the BSA mode, due only to bit crossovers in the ground link. (We are not attempting to include the effects of random bit insertions or deletions in our model of the supergroup line.) The ground link can be regarded as a binary symmetric channel with unknown crossover probability p . Because p is thought to lie in the approximate range $10^{-4} \gtrsim p \gtrsim 10^{-7}$, all computations below are to lowest order in p . The parity-check algorithm commits a byte error whenever the parity of a received byte is incorrect: a single bit crossover anywhere within a given received byte is sufficient to cause such an error. For a particular received byte, the probability ϵ_B of making a byte error is therefore given by

$$\epsilon_B \equiv \text{Pr} [\text{byte error}] = 18p \quad (1)$$

to lowest order in p . Furthermore, these errors are independent from byte to byte.

A byte error anywhere within a frame of imaging data results in the loss of the corresponding line of video, but

α bytes are transmitted over the ground link for each frame of TV data, where

$$\alpha = \frac{230.4 \times 7056}{117.6 \times 18} \text{ bytes/frame} \quad (2)$$

Therefore the probability of ϵ_L of losing a given line of a TV picture is specified by

$$\begin{aligned} \epsilon_L &\equiv \Pr [\text{lose 1 line}] \\ &= \alpha \epsilon_B = \frac{230.4 \times 7056}{117.6} p \end{aligned} \quad (3)$$

to lowest order in p . Since there are 700 lines in each picture, we can expect to lose 700 ϵ_L lines in every picture received at the SFOF. This expected loss of video is tabulated in Table 1 as a function of p .

An acceptable performance level is the loss of 1 or 2 lines of a given TV picture. To achieve this fidelity with the original formatter design, p would have to be of the order of 10^{-7} or better. Since we cannot guarantee that the supergroup channel will meet this criterion, the formatter design must be improved. The suggested changes are outlined below.

III. Improved Formatter

A. Design

The limiting problem inherent in the original formatter design is that ϵ_B is of order p . To realize any significant improvement in performance, we must change the design so that ϵ_B is of order p^2 . Because of cost considerations, the ground rules are that we can only change the last 2 bits in the D-byte shift register, the contents of the F-byte shift register, and the formatting algorithm.

Starting with the least important change, it is recommended that the original filler word be replaced by the 18-bit Neuman-Hofman sequence (Ref. 1):

$$S = 001 \ 100 \ 111 \ 110 \ 100 \ 101$$

This word has correlation properties that are particularly suited for synchronization applications, although byte synchronization is not really a problem since about half of the transmitted bytes are F bytes. The byte synchronization acquisition procedure described earlier should be retained in the new design.

Once byte synchronization is established, the receive portion of the formatter must decide whether each byte

contains data or filler. This is a standard binary hypothesis decision problem in information theory. It is assumed that the 16-bit blocks of TV data in each D byte are independent and uniformly distributed. To minimize the probability of error in deciding between F and D bytes, we want to maximize the expected Hamming distance between them. As shown in Fig. 2, this requires that the last two bits of the F and D bytes be complementary. This precludes the use of the parity-check scheme in the original formatter design.

To distinguish between D and F bytes, the receive portion of the formatter computes the Hamming distance d_H between each received byte and the known F byte. The binary decision for a given received byte is then specified by the algorithm

$d_H = 0 \text{ or } 1 \Rightarrow \text{F byte}$
$d_H > 1 \Rightarrow \text{D byte}$

The algorithm must also decide when byte synchronization is lost. We know that we can lose synchronization only because of the random deletion or insertion of bits over the ground channel. If we actually do lose byte synchronization, the binary decision procedure above will interpret almost every received byte to be a D byte. But we know we can never have more than two consecutive D bytes. Therefore, the recommended byte synchronization maintenance scheme is to reenter the BSA mode if, and only if, three consecutive received bytes are declared to be D bytes.

B. Performance

We will now compute the probability ϵ_B of making a byte error on a given received byte, due only to random bit crossovers with probability p . An F byte is misinterpreted as a D byte if two or more bits are in error; the probability of this occurrence is given by

$$\Pr [D | F] = \binom{18}{2} p^2 \quad (4)$$

to lowest order in p . The most likely way that a received D byte will be misinterpreted as an F byte is when the received 16-bit data block is identical to the first 16 bits of the filler sequence, and one of the last two bits is in error:

$$\Pr [F | D] = 2^{-16} \binom{2}{1} p \quad (5)$$

If a received F byte between two D bytes is misinterpreted while the received D bytes are correctly detected,

we will reenter the BSA mode. This is the most probable circumstance under which the BSA mode is invoked. The probability of this event is given by Eq. 4 to lowest order in p .

The fraction of transmitted bytes containing TV data is given by

$$\Pr [D] = \frac{18 \times 117.6}{16 \times 230.4} \quad (6)$$

Conversely,

$$\Pr [F] = 1 - \Pr [D] \quad (7)$$

Therefore, we conclude that

$$\begin{aligned} \epsilon_B &= \Pr [D | F] \Pr [F] + \Pr [F | D] \Pr [D] \\ &= 153p^2 + p(2^{-15} - 153p) \left(\frac{18 \times 117.6}{16 \times 230.4} \right) \end{aligned} \quad (8)$$

Since 2^{-15} is of the order of p , ϵ_B is now of the order of p^2 as desired. The probability of losing a particular line of

video is again specified by $\epsilon_L = \alpha \epsilon_B$, where α is defined in Eq. 2, and the expected video loss is 700 ϵ_L lines per TV picture.

The expected loss of video for the new formatter design is compared with the performance of the original system in the table of Fig. 3. We see that we can now anticipate the loss of less than 1 line every 3 pictures on the average, provided the ground channel exceeds its minimum estimated reliability, $p = 10^{-4}$. Since p had to be less than 10^{-7} to guarantee this performance in the original formatter, this implies a design advantage of 3 orders of magnitude with respect to the maximum acceptable crossover probability of the ground link.

IV. Conclusion

The conclusions of this report are self-evident. The original formatter design could not ensure adequate performance levels; the recommended design does. At a meeting held on May 18, 1973, the project ratified the proposed formatter design changes, and these have subsequently been implemented.

Reference

1. Neuman, F., and Hofman, L., "New Pulse Sequences with Desirable Correlation Properties," in *Proceedings of the National Telemetry Conference, Washington, D.C., April 14, 1971*, pp. 272-282.

Table 1. Performance comparison of original and new word formatter designs versus bit crossover probability p of ground link

Bit error rate, p	Expected number of lines lost per TV picture	
	Original design	Proposed Design
1 in 10^4	700	1 in 3
1 in 10^5	100	1 in 280
1 in 10^6	10	1 in 2.2×10^4
1 in 10^7	1	1 in 7.8×10^5

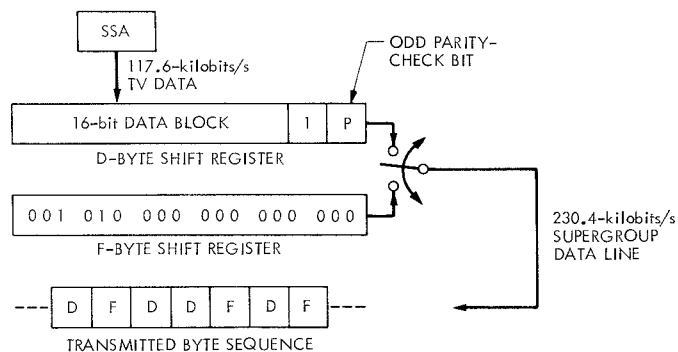


Fig. 1. Transmit portion of original word formatter design

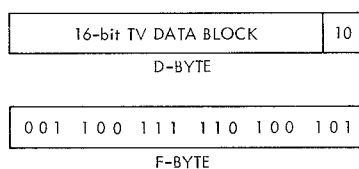


Fig. 2. Recommended formats of D- and F-byte shift registers